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TURBINE AERO THERMAL RESEARCH

Richard B. Rivir

JULY 9, 1996

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AFOSR Program Manager: **Dr. James McMichael**

Research Objectives:

- Establish fundamental understanding of heat transfer mechanisms in gas turbine engines.
- Provide an understanding of the effects of unsteady free stream turbulence on turbine blade heat transfer.
- Improve the accuracy of heat transfer predictions.
- Develop concepts and strategies for the control of turbulent heat transfer.
- Transition basic research results to the gas turbine industry and to IHPTET Technology Demonstrations

Progress for 1995-1996: The Low Pressure, Low Reynolds Number Turbine experiment have been conducted on a Langston cascade at the Air Force Academy and at UC Davis with freestream turbulence levels of 0.5%, 1%, 8% and 10%. Reynolds numbers of 67.5K, 110K, 134K, and 144K have been run. Different pitch to chord ratios and cascade flow angles significantly affect the transition and separation processes and have been documented. Pratt low pressure blade profiles are being used in the cascade experiment at WL with a moving stator section and free stream turbulence levels to 17%. Computations have been run here using the Allison Blade Vane Interaction Program for all cases investigated for the Langston cascade at AFA and UC Davis.

Extensive Particle Image Velocimetry measurements on our 2D Boundary layer high turbulence film cooling experiments have been carried out for the forced and unforced film cooling flows. The double pulsed YAG exposures provide flow visualization in addition to the vector velocity field. These photos show details such as the shear layer resulting from the film hole walls rolling up in the opposite direction to the primary flow, shear layer growth, jet spread, and the changes in film cooling flow turbulence scales with changes in freestream turbulence that have not been possible to documented with conventional measurements.

Two members of our team completed their PhD's this year. Rolf Sondergaard from Stanford University (Palace Knight) and Ed Michaels, from the University of Dayton. Dr Sondergaard received the Balhaus Award for the best Stanford Aero Dissertation for 1995. Dr Michaels worked on a two scale turbulence model for about 7 years here in our lab. His model now predicts Stanton Number and skin friction for turbulence levels of 0.5 to 20%, far more accurately than any other model (within ±2% of measured values). Dr Sondergaard's and Dr Michaels Dissertations are availble from the authors. R. Rivir and J. Bons received the 1995 S. D. Heron Award from the Aero Propulsion and Power Directorate for High Turbulence Effects on Film Cooling. R. Rivir organized and hosted the 1995 AFOSR Contractors and Grantees Meeting on Turbulence and Internal Flows. Dr Won Chang joinned the group in May of 1996. Our PIV work was selected for the American Physical Society's Gallery of Fluid Motion for 1996.

PUBLICATIONS 1996:

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J. Bons, C. D. MacArthur, and R. B. Rivir, "The Effect of High Freestream Turbulence on Film Cooling Effectiveness," Accepted for publication in the ASME Journal of Turbomachinery.

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Gogininni, Rivir, Pestian, and Goss, "PIV Measurements of Periodically Forced Flat Plate Film Cooling Flows with High Free Stream Turbulence," AIAA Aerospace Sciences Meeting, AIAA 96-0617, January 1996.

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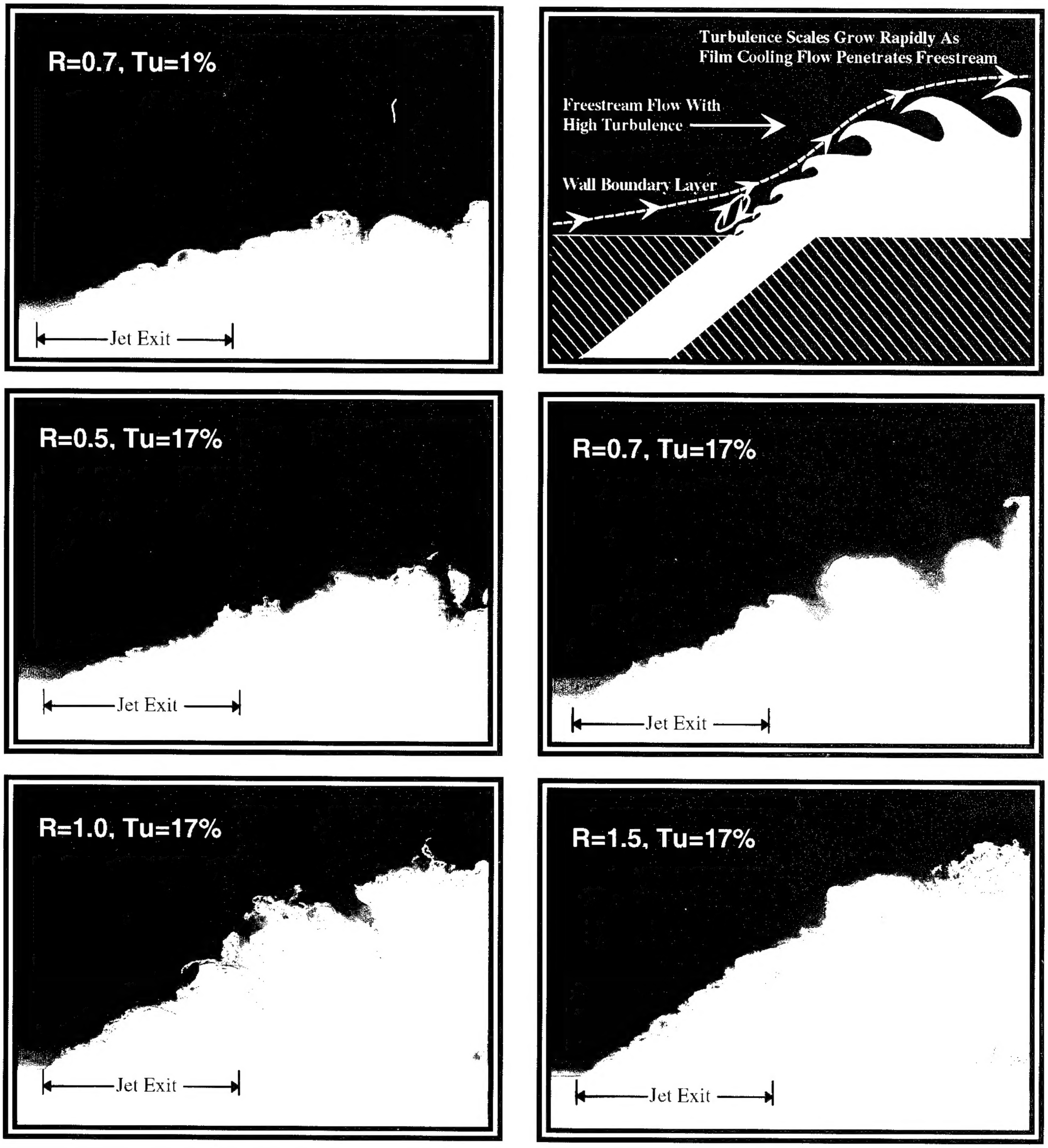
Simon T. W. and Volino R. J., "Documentation of Separating and Separated Boundary Layers," Final Report for: Summer Faculty Extension Program, Wright Laboratories, WPAFB, OH, February 1966.

Sharp, C1C J., and Harris, C2C P., "Turbulent Heat Transfer Investigation: Turbulent Length Scales and Heat Transfer," Air Force Academy Aeronautical Engineering 471, May 1996.



HIGH FREE STREAM TURBULENCE INFLUENCE ON TURBINE FILM COOLING FLOWS

Submitted by S. Gogineni (Systems Research Laboratories), R. Rivir (Wright Laboratory), D. Pestian (Univ. of Dayton Research Institute), L. Goss (Innovative Scientific Solutions, Inc.), Dayton, OH

Double pulsed two-color Particle Image Velocimetry (PIV) images of simulated turbine film cooling flows are shown for a range of film cooling blowing ratios ($R = \rho c U c \ / \ \rho \infty U \infty$) of 0.5, 0.7, 1.0 and 1.5. The simulated turbine conditions include the film cooling jet l/d = 3, film jet Reynolds number of 20,000 and free stream turbulence level of up to 17% among other characteristics described by Bons et. al. (1994). These images are obtained by seeding the jet flow only with sub-micron size smoke particles and illuminating the particles with a two-color PIV system. These images illustrate how the jet spreads and shear layer grows with two of the problem parameters, the blowing ratio and the free stream turbulence level. There is a decrease in film cooling effectiveness and increased heat transfer associated with the increase in turbulence intensity which is currently difficult to predict. PIV images and the reduced PIV data are useful in providing additional physics on mixing and dissipation for improved modeling of these flows.